Department of Naval Architecture and Ocean Engineering
Independent Research in Naval Engineering Final Report

Project Alligator

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Abstract

On 01 NOV 1861 the United States began its submarine program out of increasing fears in the capability of enemy forces, namely the CSS *Merrimac*. The result, USS *Alligator*, was in tow to a forward combat zone – Charleston Harbor – when it was cut loose due to inclement weather and presumably sunk some 50 miles south of Cape Hatteras (http://home.att.net/~jimchris/page3.html). The objective of this research is to determine the likelihood of locating the *Alligator* through current understanding of Gulf Stream / Labrador Current interaction and analysis of the structure and survivability of the submersible. This project poses significant challenges from many different areas, as well as technical and non-technical fields. The use of historical documents as well as modern engineering techniques is necessary in order to explore the fate of the *Alligator*. The naval significance of this undertaking is clearly defined by the parallel interest of the Navy in its first ironclad, the *Monitor*. The potential for this project is enormous and could involve heavy Naval Academy interaction with NOAA and the Office of Naval Research.

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Introduction

The invention of the submersible is by no means a recent creation. Inventors have been toying with the idea as early as the late 1500s. Some of the earliest models include the *Rotterdam* by Frenchman De Son in 1653 and the *Turtle* by American David Bushnell in 1776.[1] The brain behind the *USS Alligator* was Frenchman Brutus DeVilleroi. Prior to his work on the *Alligator*, DeVilleroi had 25 years of experience building and testing submersibles. He was not brought to the attention of the Americans until he was arrested off the coast of Philadelphia while testing a 35-foot submersible very similar to the *Alligator*. This aroused the attention of Captain DuPont from the American navy who later spurred DeVilleroi to write to President Abraham Lincoln and Secretary of the Navy Gideon Welles about purchasing this small submersible. Welles was interested in DeVilleroi's work, but felt that the existing submersible was too small for the needs of the navy. He then hired DeVilleroi under contract to build a larger vessel, which became the *USS Alligator*. This is the first submersible designed and built for the US Navy.[2]

The *USS Alligator* began construction on November 1, 1861 and was not launched until May 1, 1862 from the Philadelphia shipyard of Neafie and Levy. The original design by DeVilleroi was propelled through the water with the work of sixteen crewmen to row the Alligator. There were eight hinged oars on either side that folded inward on the forward stroke and open up on the draw stroke. This enabled the submersible to be propelled through the water at a speed of three to four knots.[3] The purpose of designing the submersible with oars on either side was to increase maneuverability so that it could change directions much like a rowboat. However after much testing, the oars proved to be inefficient. The oars on the Alligator were then replaced with a propeller and the opening for the oars were patched up.

The mission of the Alligator was to deploy limpet-type mines attached to the enemy vessel by sending divers through the diver's access hatch located near the bow. In order for the submersible to operate properly, over seven and a half feet of water were required. A stationary ballast attached to the keel was used in order to control the depth. The hull of the Alligator was made out of wrought iron plates that had been rolled and joined with countersunk rivets in order to create a smooth body with less drag.[4] Wrought iron is the oldest form of iron dating back at least four thousand years that has a very low carbon content. This material is no longer used for structural purposes because of improvements made in the steel industry. However it is very strong in tension and is not as susceptible to corrosion.[5] The *Alligator* was in tow by the *Sumpter* on the way to Port Royal for its first mission when a heavy storm forced the *Sumpter* to cut the towline loose. The *Alligator* was lost on April 2, 1863 off the coast of Cape Hatteras.

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[1] Captian Brayton Harris, "World Submarine History Timeline 1580-2000" http://www.submarine-history.com/NOVAone.htm
[2] James Christley, "The Alligator: The North's Underwater Threat," *Civil War Times Illustrated*, February 1981, 26-31.
[3] Christley, 29.
[4] Ibid, 30-31.
[5] D. H. Wakelin and J. A. Ricketts, " The Nature of Ironmaking," (Pittsburgh: The AISE Steel Foundation, 1999), 2.

Theoretical Analysis

There are several factors that must be addressed in order to make an educated decision on the search radius for the *Alligator*. The areas of research for this project were limited to the structural analysis including the corrosion properties as well as the rates at which the submersible would sink once cut loose from the *Sumpter*.

Structural Analysis

The most challenging aspect of the Alligator as an engineer is the lack of information on the structure and how it was built. Because no blue prints were left behind, many assumptions based on historical documentation were made regarding the dimensions and construction of the submersible. The basic design chosen for testing was a compressed cylindrical body with conical ends at the bow and stern. This was the most logical shape based on the technology of the time period. The submersible was determined to have the following dimensions:

Length	45 feet (not including the shaft)
Width	4.5 feet
Height	6 feet
Volume	761.55 ft^3
Displacement	21.77 LT

Table 1: Dimensions of the *Alligator*

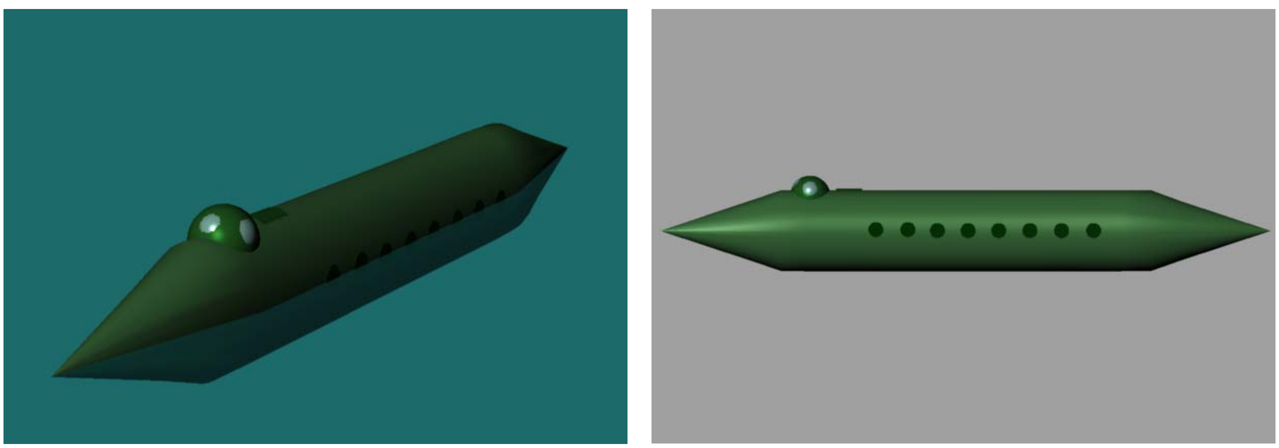

Figure 1: Rhino 3D model of the *Alligator*

Although a scale model of the *Alligator* was not practical based on the limited resources of the hull design, a computer generated Rhino model was developed instead using the dimensions assumed in Table 1. This model was helpful in calculating the surface area, volume, and displacement of the submersible along different waterlines. The dimensions of Table 1 were also used to create a table of offsets (see Appendix A), which could then be used to determine curves of form for the *Alligator* (Figure 2).

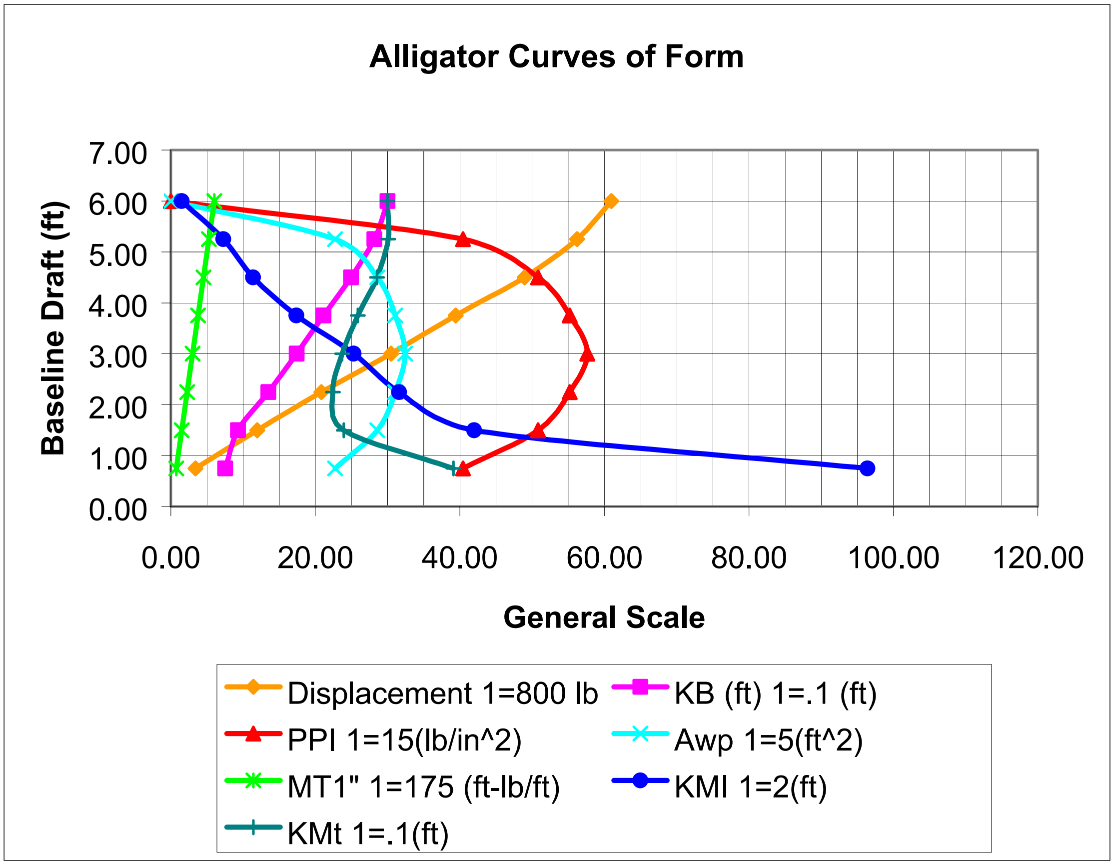

Figure 2: Curves of form for the *Alligator*

The curves of form represent the following factors:

Awp- Area water plane
KM_t- Distance from keel to transverse metacenter
KB-Height of center of buoyancy above keel
KM_l- Distance from keel to longitudinal metacenter
MT1- Moment to change trim one inch
PPI 1-Pounds per inch to lower one inch

Figure 2 illustrates the various stability factors of the *Alligator* along with the displacement of the submersible based on the baseline draft. From this data the submerged displacement of 21.77 LT and a volume of 761.55 ft^3 were calculated. This information will be helpful in determining the survivability of the *Alligator* after it was cut loose from the *Sumpter.*

Leakage rates/ Floating time

Finding leakage rate and floating time of the *Alligator* is significant to locating the Alligator because leakage could affect the movement of the submarine and its sinking velocity. According to historical documents, which describe the moment when the crew of the *Sumpter* cut the towing lines pulling the *Alligator*, the *Alligator* disappeared quickly from sight. With only this description, it can only be estimated when it sunk from the sight of the crew and hit the bottom of the seafloor. However, some structural failures that the *Alligator* had, which were reported by its commanders during the testing and evaluation period before launch, might have recurred again under the extremely strong storm and the high-pressure of deep water.

In January to February of 1863 the *Alligator* had a propeller installed to replace the original oars in order to increase her speed. Because of the installation of the propeller and the removal of 16 oars of the *Alligator*, her dimensions had changed to longer and more conical shape in the rear. Reconstruction of the *Alligator* could increase the structural failures related to leakage or maneuverability. The leakage problem is the greatest concern in construction of a submarine because a submarine operates under very high water pressure so it faces extremely large pressure differential between inside and outside of the submarine. Even though a hole or hatches are totally sealed, water with high pressure can easily seep into a submarine.

USS Alligator is considered to have potential sites for cracks, especially, the 16 holes where the oars had been located. In addition to the oar holes, the two hatches for both the crew and the divers could be the second significant leak site. As *Alligator* submerged, the seams where the iron plates were connected could potentially leak. It is likely that the observation glass on the observation dome would not be able to tolerate the tremendously high pressure outside of the *Alligator* as well.

However, it is not known which site could be leaking and at what rate because of what kind of techniques DeVilleroi used for sealing submarine's surface. As the *Alligator* submerged, one could see how well the Alligator was constructed. Therefore, calculating the maximum and minimum leakage rates of *USS Alligator* is required, instead of finding the exact leakage rate.

The leakage rates are used to calculate the floating time of the submarine from when it was released from the towing vessel until it became negatively buoyant. With the dimension used in Table 1, the Alligator is estimated to have a submerged displacement of 21.76 long tons and a surface displacement of 11.49 long tons. The difference of these two displacements, 10.27 long tons or 23,021.5 lbs, is the maximum amount of water that the *Alligator* is allowed to have to become negatively buoyant. Therefore, if leaking water entered more than 23,021.5 lbs, she would lose her buoyant force and start to sink. One thing we should consider at this point is that 23,021.5 lbs of water is the sum of the leaking water and the water, which was already in the water tank of the Alligator.

However, one does not know how deep the *Alligator* had been towed therefore it is difficult to figure out how much water was in the water tank. For this reason, an assumption is made that there was no water inside of the *Alligator* when she had been towed and this assumption would result a greater floating time than the actual floating time.

The calculations of both maximum and minimum leakage rates are based on the theory of conservation of energy. As seen in the equations below, $P_{outside}$ is the pressure of water on the surface of the *Alligator* and P_{inside} is the interior pressure of the *Alligator*. P_{inside} is assumed to be one atmospheric pressure. However, in the real situation, the inside of the *Alligator* was considered to be pressurized to one atmosphere, which is 14.7 psi.

$$\dot{Q} - \dot{W} - (L\dot{O}SS) = \frac{dE_{system}}{dt}$$

$$\rightarrow \dot{Q} - \dot{W} - \dot{L} = \sum \dot{m}_{out}\left(\frac{V^2}{2g} + \frac{P}{\gamma} + Z\right)_{out} - \sum \dot{m}_{in}\left(\frac{V^2}{2g} + \frac{P}{\gamma} + Z\right)_{in}$$

$$\rightarrow \frac{\dot{Q}}{\dot{m}g} - \frac{\dot{W}}{\dot{m}g} - \frac{\dot{L}}{\dot{m}g} = \left(\frac{V^2}{2g} + \frac{P}{\gamma} + Z\right)_{out} - \left(\frac{V^2}{2g} + \frac{P}{\gamma} + Z\right)_{in}$$

Because there is no heat transfer (Q) and no mechanical work loss (W), the below equation is derived.

$$\rightarrow -\frac{\dot{L}}{\dot{m}g} = \left(\frac{P}{\gamma}\right)_{out} - \left(\frac{V^2}{2g} + \frac{P}{\gamma}\right)_{in}$$

Where $\dot{Q}$ is the heat rate [J/sec]

$\dot{W}$ is the mechanical working rate [J/sec]

$L\dot{O}SS$ is the loss energy due to frictions [J/sec]

V is the velocity of fluid [ft/sec]

P is the pressure [atm]

Z is the elevation of object [ft]

$\dot{m}$ is the mass flow rate [lbm/sec]

γ is the specific volume [lb/ft^3]

g is the acceleration due to gravity [ft/sec^2]

Since $\frac{\dot{L}}{\dot{m}g} = K\left(\frac{V_{out}^2}{2g}\right)$. K is the frictional loss coefficient and V_{out} is the velocity of leaking fluid.

$$\rightarrow -K\left(\frac{V_{out}^2}{2g}\right) = \frac{(P_{out} - P_{in})}{\gamma} - \frac{V_{in}^2}{2g}$$

$$\rightarrow V_{out}^2 = \frac{2(P_{in} - P_{out})}{\rho(1 - K)}$$

Where $V_{out} = \frac{\dot{Q}_{leakage}}{A}$ and $\dot{Q}_{leakage}$ is the leakage rate (different from the heat rate of $\dot{Q}$)

A is the size of crack

$$\rightarrow \left(\frac{\dot{Q}_{leakage}}{A}\right)^2 = \frac{2(P_{in} - P_{out})}{\rho(1-K)}$$

$$\rightarrow \dot{Q}_{leakage} = \sqrt{\frac{2(P_{in} - P_{out})}{\rho(1-K)}}A$$

Where P_{in} = 1 atm

$P_{out} = (\rho_{\text{sea water}} * g)$

ρ is the density of fluid.

The maximum and minimum leakage rates can be plotted from the equation above, as assuming the Alligator was at certain depths of water with the 10ft increments up to 300ft. The frictional coefficient, K is zero for the minimum leakage rate while it is 0.999 for the maximum leakage rate. According to the graphs, the leakage rates are proportional to the *Alligator*'s total crack size and they are increased as the *Alligator* sinks down every 10 ft of water. Figure 3 shows the maximum leakage rates.

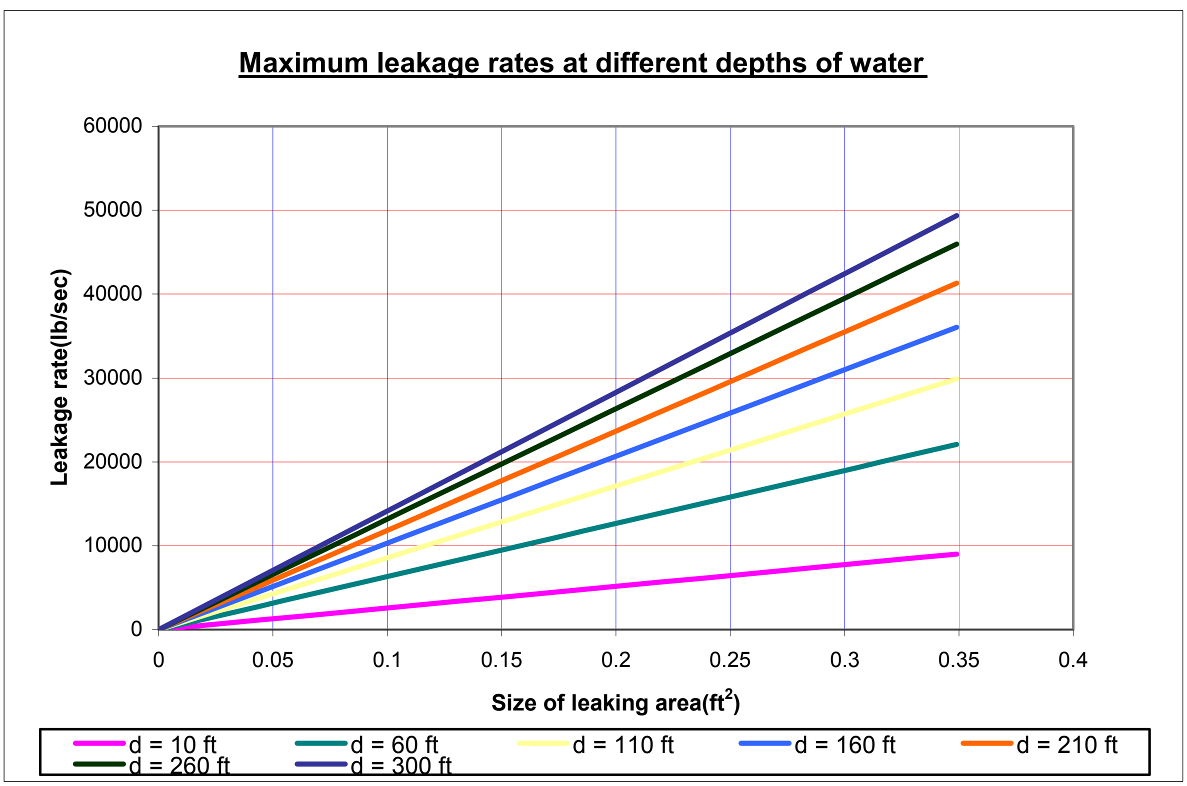

Figure 3: Maximum leakage rates

The following graph shows the floating time of the *Alligator* using the maximum leakage rates.

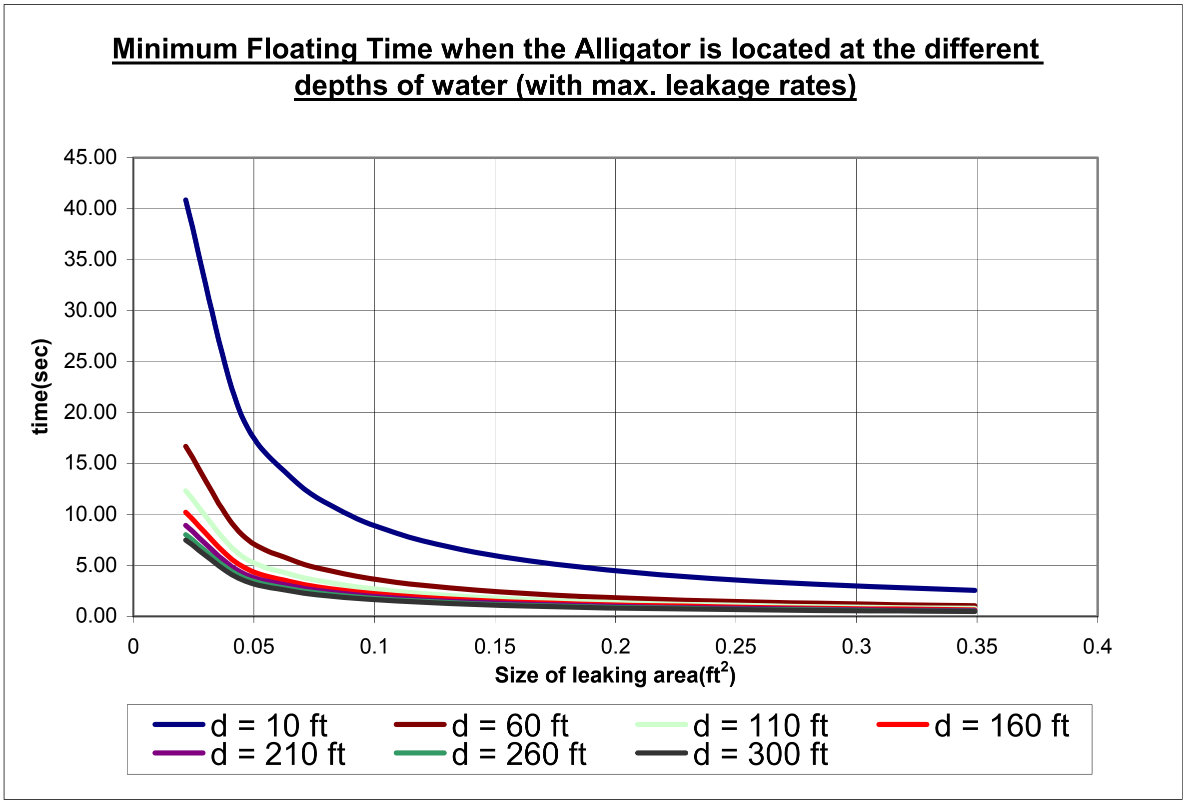

Figure 4: Minimum floating time

Based on the plots, the possible floating times can be found with these leakage rates and the maximum weight of water, 23,021.5 lbs, that the *USS Alligator* can hold inside. However, while looking at the plots of the floating time, one sees that if the total crack size is very small, the floating time is infinite. This means the *Alligator* could be still floating. The graphs of the floating times versus the sizes of the total crack shows that as the *Alligator* sinks down and the size of the crack increases, the floating time is decreased due to higher mass flow rate. Table 2 shown below displays the possible floating time as the total crack size of the Alligator is increased.

	Minimum floating time of the Alligator (sec)					
	Depth of water where the Alligator is floating (ft)					
Total crack size (ft^2)	**d = 10 ft**	**d = 60 ft**	**d = 110 ft**	**d = 160 ft**	**d = 210 ft**	**d = 300 ft**
0.02	40.9	16.7	12.3	10.22	8.9	7.5
0.09	10.2	4.2	3.1	2.6	2.2	1.9
0.15	5.8	2.4	1.8	1.5	1.3	1.1
0.2	4.5	1.9	1.4	1.1	1.0	0.8
0.28	3.1	1.3	1.0	0.8	0.7	0.6
0.35	2.6	1.0	0.8	0.6	0.6	0.5

Table 2: Minimum floating time

To predict more accurate leakage rates and floating times, more historical descriptions and engineering analysis of the Alligator at that time are needed. Therefore, it will be more reasonable to find out the minimum leakage rate and the maximum floating time of the *Alligator*. The minimum leakage rates and floating time are shown in Figure 5 and Figure 6.

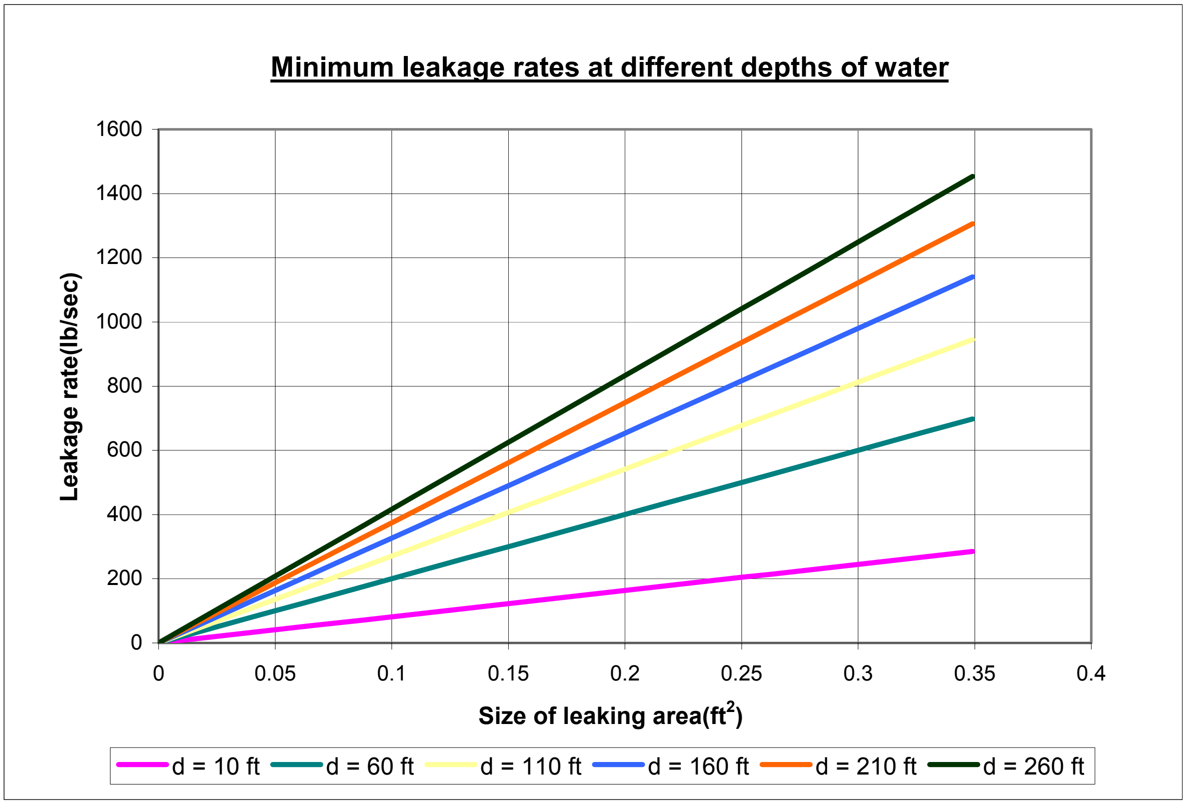

Figure 5: Minimum leakage rates

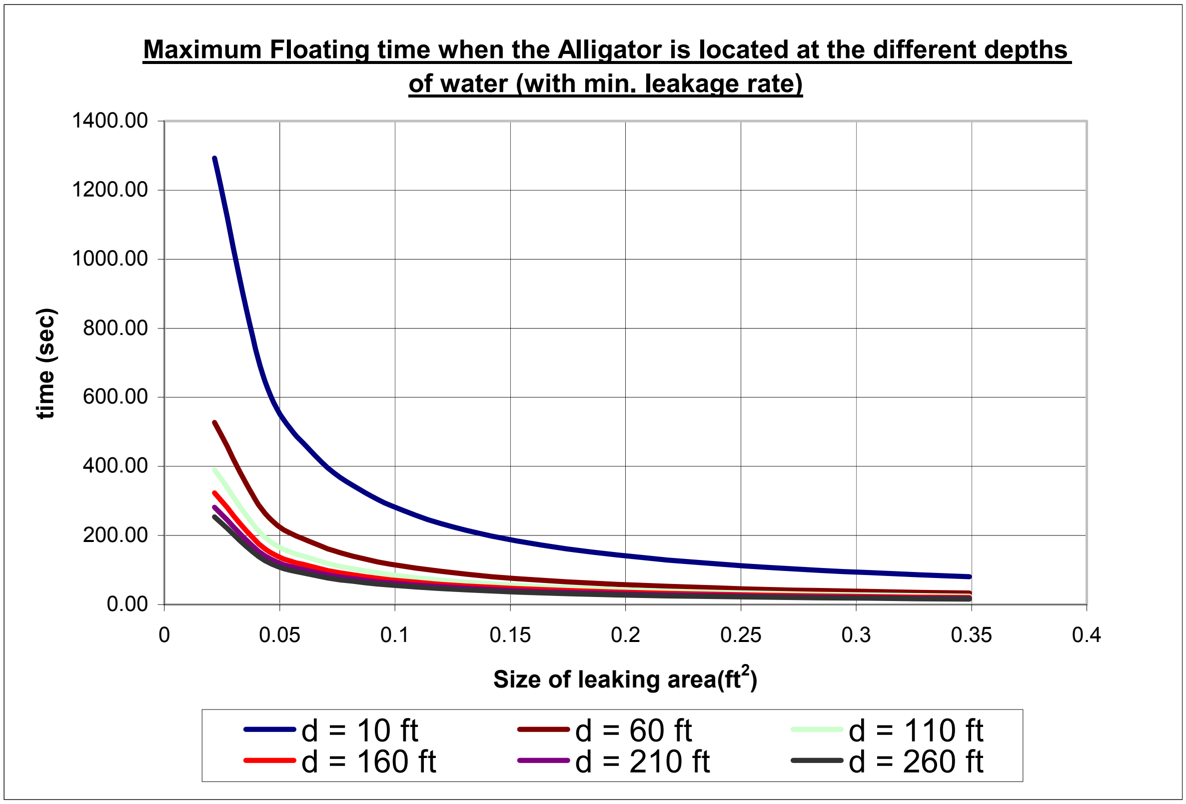

Figure 6: Maximum floating time

	Maximum floating time of the Alligator (sec)					
	Depth of water where the Alligator is floating (ft)					
Total crack size (ft^2)	**d = 10 ft**	**d = 60 ft**	**d = 110 ft**	**d = 160 ft**	**d = 210 ft**	**d = 300 ft**
0.02	1292.4	527.6	389.7	323.1	282.0	236.0
0.09	323.1	131.9	97.4	80.1	70.5	59.0
0.15	184.6	75.4	55.7	46.2	40.3	33.7
0.2	143.6	58.6	43.3	35.9	31.3	26.2
0.28	99.4	40.6	30.0	24.9	21.7	18.2
0.35	80.8	33.0	24.4	20.2	17.6	14.8

Table 3: Maximum floating time

The leakage rates are used to find the floating time until the *Alligator* becomes negatively buoyant. However, the assumption for calculating leakage rates, with the interior pressure of the *Alligator* equals to one atmosphere, could be obtained more precisely since the amount of leaking water inside of the submarine has been increased, the inside pressure has been increased due to decreasing of the free volume inside the *Alligator*. For this, the Boiler's law could be useful.

Vertical location of the Alligator and Sinking Time

The sinking rates are different from the leakage rates. The sinking rates occur after the Alligator became negatively buoyant while the leakage rates were when the *Alligator* maintained its positive buoyancy. Therefore, the sum of floating time based on the leakage rates and the sinking time based on the sinking rates is the total time from when the *Alligator* was released until it hit the bottom of the seafloor. During the analysis of the vertical location and sinking time, an assumption was made that the interior pressure equals to one atmospheric pressure. However, to obtain more accurate values of sinking rates, the actual interior pressures of the *Alligator* at different depths of water are recommended to calculate based on the Boiler's law.

For the sinking rates to be calculated, the initial depth of the *Alligator* was assumed to be 7.5 feet. This value is based on the minimum water depth of 6 feet, operable for the *Alligator*, plus the extra water depth of 1.5 feet for the diver to enter and exit the vessel. The vertical location of the *Alligator* versus sinking time has been calculated in 60 seconds interval. To derive the equation for vertical location and sinking time of the Alligator, all factors, which affect to movement of the *Alligator* vertically, are considered. The below equation is when the *Alligator* is in a stable state in the water.

$$\sum F_z = F_B + Drag_z - W(t)$$

Where F_z is the force in the vertical direction on the *Alligator* [lbs]
F_B is the buoyant force of the *Alligator* [lbs]
$Drag_z$ is the vertical directional drag force on the *Alligator* [lbs]
W is the weight of water, which enters inside of the *Alligator* [lbs]

The basic calculation for sinking time is derived from the equation above, which includes the drag force to the equation for the leakage rates. The differences between the inside and outside pressure of the *Alligator* are calculated in every 60 seconds of sinking time. As seen in the equations below, the leakage rates would increase once the *Alligator* had 23,021.5 lbs of water (F_B-W_S = 0), when it became negatively buoyant and began to sink. The terminal velocity, U_Z, of the downward movement of the *Alligator* was needed in order to figure out the depth the *Alligator* had sunk. To find the terminal velocity at the 60 second interval, the downward drag force is made as a function of time. The terminal velocity of the *Alligator* increases until it is entirely filled with water. Because the *Alligator* already has 23,021.5 lbs of water before it sinks, the amount of water to fill the *Alligator* completely is calculated by [the amount of water that the Alligator can hold inside, 36,235 lbs] - [23,021.5 lbs of water], which results in 13,213.5 lbs of water.

$$\sum F_z = F_B - W_S + Drag_z - W(t)$$

$$W(t) = Drag_z = \frac{1}{2} C_D \rho (U_z)^2 A_z$$

Where U_z is the terminal velocity of the *Alligator* toward the seafloor direction. [ft/sec]
C_D is the drag coefficient of the *Alligator*
A_z is the cross sectional area of the *Alligator* [ft^2]

Once the *Alligator* is completely filled with water, the terminal velocity is constant due to the assumption that there is no acceleration in downward movement of the *Alligator*. Table 4 shows the sinking properties when the *Alligator* is totally filled with water.

Total size of cracks on the surface of the *Alligator* (ft^2)	Time when the *Alligator* is totally filled with water (sec)	Elevation of the *Alligator* at this time (ft)	Terminal Velocity of the *Alligator* (ft/sec)
0.02	174	1167.6	5.17
0.04	134	538.1	6.65
0.09	90	397.2	7.29
0.17	67	304.3	7.42
0.35	47	247.4	8.69

Table 4: Sinking properties

Figure 7 below shows the depth of the *Alligator* in respect to the time after it sank. Also, knowing the sinking time it can be analyzed when and where the *Alligator* hit the bottom of the seafloor if the depth of seafloor is known where it is lost. As the leakage rates that we discussed above are dependant on the total crack size on the surface of the *Alligator*, the sinking times are varied by the total size of the cracks as well. As seen in the plot, the depth is proportional to the time since the inside of *Alligator* was totally filled with water due to the constant terminal velocities and the average velocities of the *Alligator*.

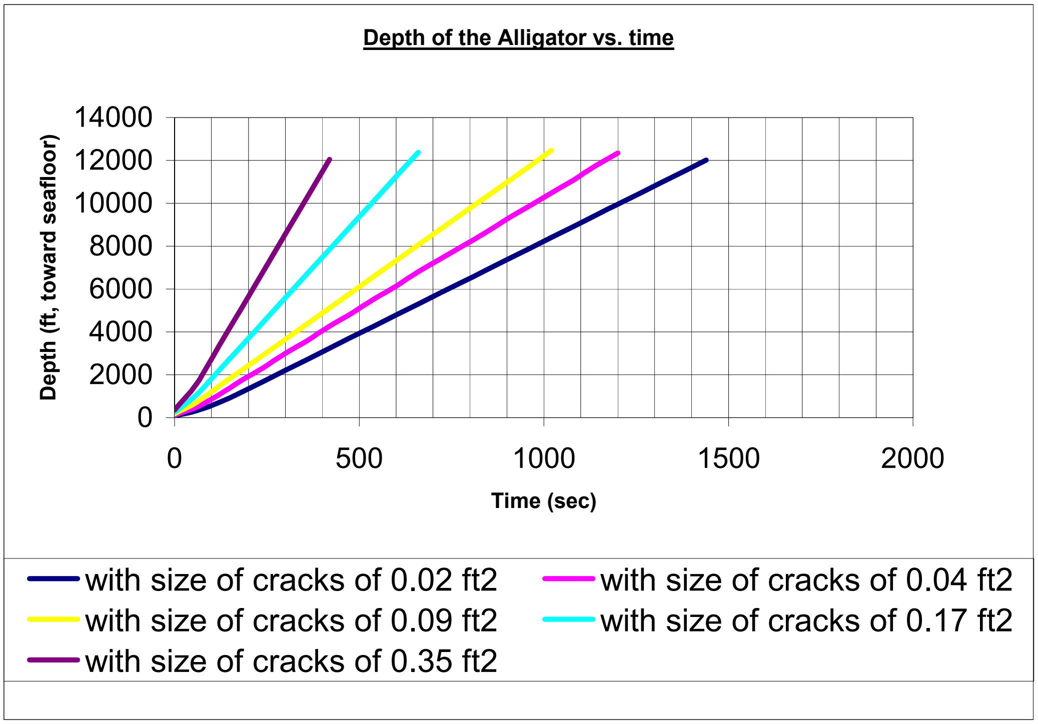

Figure 7: Depth of *Alligator*

Figure 8 shows the vertical average terminal velocities of the *Alligator* versus the depth of the *Alligator* toward the bottom of the seafloor while it sinks. As mentioned above, the terminal velocity would be constant once the *Alligator* is totally filled with the water.

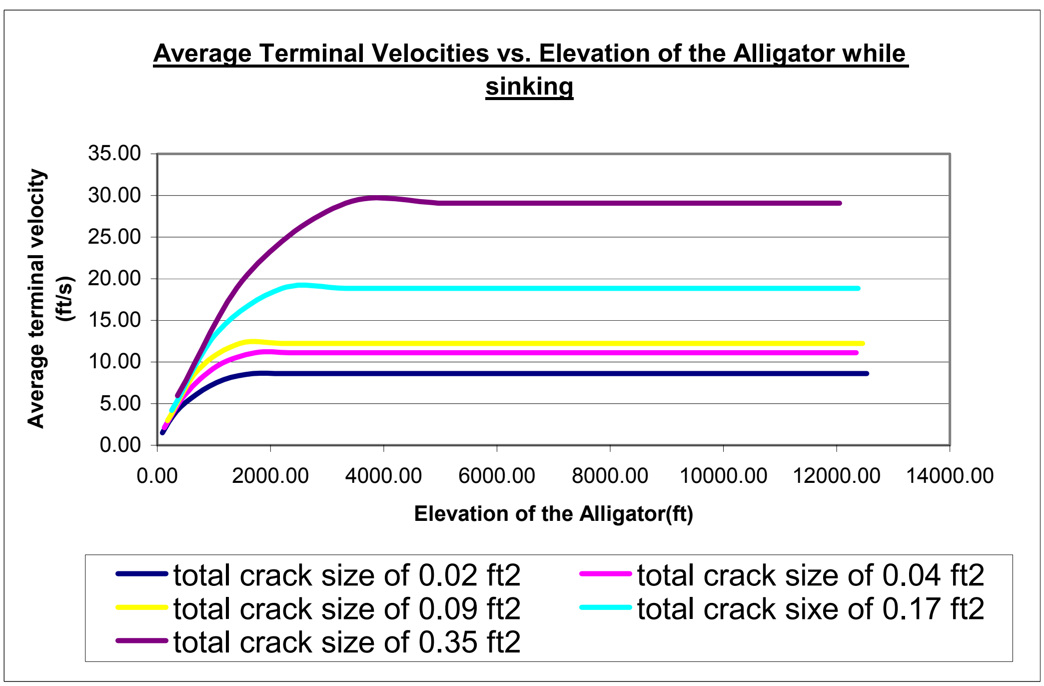

Figure 8: Terminal velocity of *Alligator*

Corrosion

The study of corrosion in the marine habitat is unlike any condition that can be replicated or observed in an experimental setting. This is due to the numerous factors and variables that affect the rate at which materials decay in the ocean. There are two aspects to pay attention to, the composition of the material and the environment in which it is found. The most probable material during that time period that was used for the Alligator was wrought iron. This form of steel is very similar to pure iron because there are few impurities. It contains less than 2% carbon by weight.[6] One of the main reasons that wrought iron was selected over steel was because of its ability to resist corrosion.[7] Wrought iron is also known for its material toughness, which is partially due to the addition of slag within the steel. Slag in a non-rusting glass like fiber, which forms about 1% to 3 % of the composition of wrought iron in quantities of 200,000 fibers per inch of cross section.[8] The slag is mixed into the material mechanically in order to provide added strength and durability. The absence of impurities also makes the wrought iron more magnetic, which will aid in the location process.

Every shipwreck will be affected differently by corrosion depending on location; therefore it is impossible to compare the *Alligator* with other recovered artifacts. However looking at other sites can be helpful because it may prepare divers for what to expect when they locate the *Alligator*. The long-term rate of corrosion in seawater for wrought iron is around .1 mm/year. This assumes an ideal case without the affects of concretion, or galvanic coupling. If this rate holds true, then after 140 years, 14 mm or .55 inches will have corroded. The Alligator is believed to have a wall thickness of .25 inches, which means it would no longer exist. It is likely that outside factors have played a large role in corrosion rates.

These factors include water composition, temperature, marine growth, seabed composition, depth of burial beneath the seabed, and extent of water movement.[9] The factors may have a retarding affect on the corrosion rate and can explain why artifacts last for so long on the ocean floor. This can be seen when looking at other wrecks from the same time period. One specimen, the *USS Hunley*, was built in 1863 for the Confederate Navy and was the first submersible to successfully sink a warship.[10] The *USS Hunley* is a perfect example because it was found in August 2000 after having sunk over 130 years ago off the coast of Charleston buried under a protective layer of sand and shell particles.[11]

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[6] Colin Pearson, *Conservation of Marine Archaelogocal Objects*, ed. Stephen G. Rees-Jones (London, Butterworth & Co, 1987), 77.

[7] Bradley Stoughton, *The Metallurgy of Iron and Steel,* 4th ed.(New York: McGraw –Hill Book Company, Inc, 1934), 54-57.

[8] James Aston and Edward Story ,"Wrought Iron - Its Manufacture, Characteristics, and Applications" (The A. M. Byers Company, 1936 [cited 15 April 2003]); available from http://www.blacksmiths3.com/wrought.htm; INTERNET.

[9] Pearson, 68.

[10] "*H. L. Hunley*, Confederate Submarine" (Washington Navy Yard [cited 30 April 2003]); available from http://www.history.navy.mil/branches/org12-3.htm; INTERNET.

[11] "*H. L. Hunley*, Confederate Submarine" (Washington Navy Yard [cited 30 April 2003]); available from http://www.history.navy.mil/branches/org12-3.htm; INTERNET.

The survivability of the *Alligator* on the bottom of the ocean floor depends heavily on the depth to which it sank. Since this fact is unknown, it is important to take a look at the various factors that affect corrosion of metals at different water depths. Basic corrosion occurs when a metal is placed in water with oxygen present. The following reaction takes place in the case of iron[12]:

$$4Fe + 2H_2O + 3O_2 \rightarrow 4FeO(OH)$$

The oxygen levels in the water decrease with depth and are also restricted by marine growth and pollution. However when the oxygen levels become reduced and are less than the hydrogen potential levels, the main cathodic reaction becomes:

$$2H^+ + 2e^- \rightarrow H_2$$

When this process occurs, nature adapts to these needs and a sulphate-reducing bacteria begins to feed off the growth on the wreck, which speeds up the hydrogen reaction.[13] This corrosion occurs in the marine concretion layers of the wreck. Marine concretion is merely the "growth of marine organisms on artifact surfaces."[14] This layer, predominately calcium carbonate, $CaCO_3$, grows over the wreck and forms a protective boundary that reduces the effects of corrosion caused by outside factors. Therefore if this layer does not have an opportunity to form, then the harsh environment on the sea floor due to water movement and oxygen levels will not preserve the remains. Another benefit of the concretion layer is that over time as the artifact corrodes away, the original shape will be left behind by the mold formed from the growth.

Temperature is yet another factor affecting the rate of corrosion and many of the other causes are dependant upon it. When the water is free of biological growth and concretion, a 10° increase in temperature will double the rate of corrosion.[15] Therefore in deeper waters where the temperature drops off, corrosion due to temperature becomes less of a factor. It also is not as important in the case of the Alligator, because wrought iron supports marine concretion, therefore improving the survivability. Another factor however that complicates marine growth is the water movement on the sea floor where the wreck is located. This movement will prevent the protective layer of growth from forming on the wreck as well as cause the metal to erode faster. The extreme of this effect may also cause the wreck to be moved around or large debris to bump into the hull, which will produce more cracks and crevices for corrosion to occur.[16]

Galvanic coupling is another cause of corrosion that deals with dissimilar metals in contact with each other. There is no record of the materials used for the *Alligator*, however based on the study of other ships during the time period, it can be inferred that several materials were also present on the *Alligator*. When the *USS Hunley* was recovered it was found to contain cast iron, brass, glass, rubber, and textiles in addition to

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[12] Pearson, 69.
[13] Ibid, 75.
[14] Ibid, 76.
[15] Ibid, 74.
[16] Ibid, 75.

wrought iron.[17] Therefore because it was built during the Civil War era these findings should be taken into account for the *Alligator* as well. The effects of corrosion on the *Alligator* cannot be determined until it is found, however it is important to have an appreciation for the condition that the submersible will be in when it is found.

Conclusion

The purpose of the Midshipmen team was to assist the Office of Naval Research and National Oceanic and Atmospheric Administration in their search for the *USS Alligator.* The possibility of locating this lost submersible was not practical for the beginning stages the project is in, however it remains the goal for the next few years to come. The engineering team for this project has learned that in order to understand engineering, an appreciation for history must first be considered. The *USS Alligator* is only one of numerous inventions of the brilliant minds from the past that illustrates the progress engineers have made over the years.

This project is unlike a typical research project because the data is based on theoretical analysis rather than experimentation. Therefore exact values cannot be determined at this time, but rather extremes that bound any possible conditions that could exist. For instance, rather than finding an exact location where the *Alligator* may have settled, a range of values were calculated based on maximum and minimum sinking rates. Likewise, corrosion cannot be defined for this particular case, but a general idea of the best and worst case scenarios can be identified.

There are many areas that can help narrow the search for the *Alligator* that have not been researched which include the horizontal movement while sinking due to the Gulf Stream and other currents. Once this value is determined, a vector of the horizontal and vertical sinking rates can be calculated to obtain a potential search area for the *Alligator.* Figure 9 illustrates this principle. Once a search area is defined, the magnetic properties of wrought iron can be used to search for the *Alligator*. A similar technique was used to discover the *USS Monitor*. These additions to the research project will help narrow the search for the *Alligator*.

[17] "H. L. Hunley Archaeology Management Plan." SCIAA Hunley Project Working Group [cited 28 April 2003] ; available from <http://www.cla.sc.edu/sciaa/hunley4.html#six>; INTERNET.

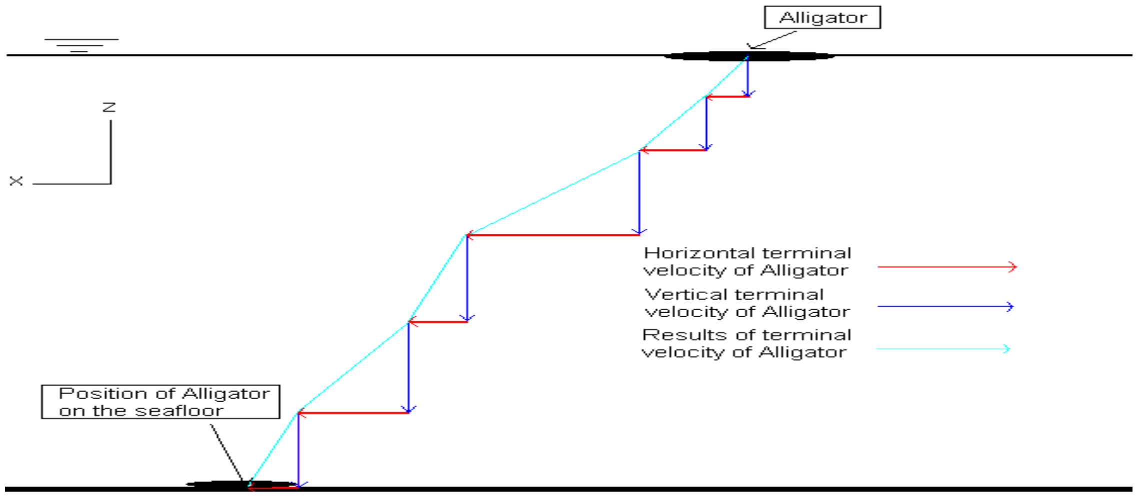

Figure 9: Future Work

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Appendix A
Table of Offsets

Appendix B
Leakage Rates

Appendix C
Sinking Properties